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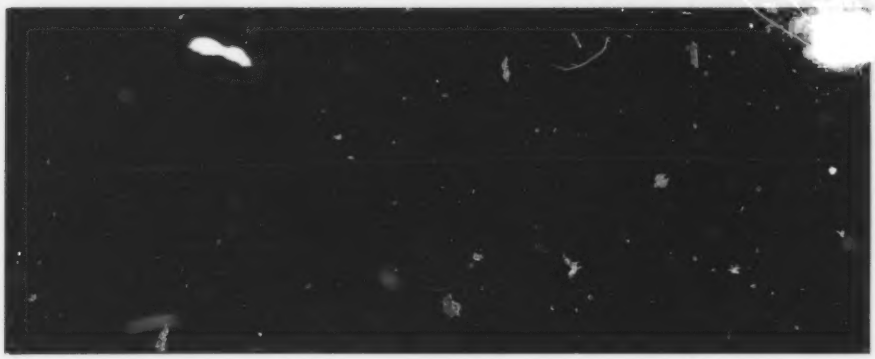

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Final Report

3.1-12

The Effect of Long-Term Rotations on the Active Fraction of Organic Matter and Soil Tilth

Conducted by Department of Soil Science
University of Saskatchewan

Funded by the Agriculture Development Fund

3.1-12

Final Report

The Effect of Long-Term Rotations on the Active Fraction of Organic Matter and Soil Tilth

Saskatchewan Agricultural Development Fund

Project No. 3.1-12

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ABSTRACT

The effect of two and three year wheat-fallow rotation, continuous wheat and a six-year wheat-fallow-hay rotation on soil organic matter and tilth of clayey Black soils was evaluated. The rotations were began in 1988 at Indian Head. Despite a general loss of soil from the plots due to movement during tillage and to erosion, organic matter contents and soil aggregation were enhanced under the continuous and hay rotations. These two rotations had larger and more active microbial populations that were able to produce more plant available nitrogen and sulphur from the organic matter. Soil losses were highest and organic matter contents lowest in the wheat-fallow rotation that was not fertilized.

EXECUTIVE SUMMARY

The effects of long-term rotations on soil organic matter, particularly the active fraction and microbial biomass, and soil physical properties were evaluated. The rotations were set up in 1958, and located on Black heavy clay soils at the Indian Head Experimental Farm. The rotations included fallow-wheat (FW), fallow-wheat-wheat with straw removed (FWW, N+P -straw), fallow-wheat-wheat with straw returned (FWW, N+P +straw), continuous wheat (Cont. W) and 6-year rotation with brome-alfalfa-hay (FWWHHH). The FW and FWWHHH rotations were not fertilized, with nitrogen (N) and phosphorus (P) fertilizer applied to other rotations, first at standard and comparatively low rates, and by soil test recommendation since 1978.

The study included replicates from Ranges 2, 3 and 4 because of the consistent occurrence of more sandy and less clayey soils in Ranges 5 and 6, and the effect of an adjacent tree shelterbelt on Range 1. The systematic examination of soils along transects indicated that organic matter-enriched A (Ap and Ah) horizons were thickest under FWWHHH, at 18 cm on average, and thinnest under FW and FWW at 14 cm. The thinner Ap horizons are consistent with substantial losses of soil, both dragged from the plot areas during tillage and by wind erosion, as indicated by estimates of soil loss using the cesium method. The FW rotation appears to have lost 8 cm of topsoil during the 30 year course of the rotation study.

Organic matter, as shown by organic carbon (C) measurements, was lowest in the FW, intermediate in the FWW (with no effect due to straw removal) and highest in Cont. W and FWWHHH. All soils had less organic matter at present than they did at the onset of the experiment in 1958.

Organic N and mineralizable N were highest under FWWHHH and Cont. W, and the soil microbial populations were larger and more active. Mineralizable sulphur (S) was highest in the same rotations, but total S was reduced under the hay rotation, probably because of higher uptake and removal of S in the forage, especially the alfalfa.

Despite a general impression of more friable and better-aggregated soil under the Cont. W and FWWHHH during sampling, detailed evaluations of soil tilth and structure generally did not show differences due to rotation. Bulk densities, soil strength (hardness) and draft requirement were not different statistically. Aggregation, particularly the formation of larger aggregates to reduce susceptibility to wind erosion, was improved under FWWHHH and Cont. W.

This study has indicated the critical need for estimating soil variability and soil loss (either because of tillage or erosion) in evaluating the effects of crop rotation on soil properties. All the treatments in this study appear to have lost substantial amounts of soil, which would have important effects on organic matter and related properties. Soil losses were least, however, under the Cont. W and FWWHHH, and the highest organic matter contents were maintained, and aggregation was improved. This indicates the soil-conserving attributes of the Cont. W and FWWHHH rotations in comparison to FW or FWW rotations.

BACKGROUND AND OBJECTIVES

This study evaluated the effects of crop rotations on the organic matter and tilth of soil. The crop rotations were set up in 1958 on the Agriculture Canada Experimental Farm at Indian Head. Eleven crop rotations were established initially, with the kind of crop and crop sequence reflecting management practices of the 1950s (Zentner et al. 1987). The plots were large enough (4.5 metres wide by 33.5 metres long or 14 feet by 108 feet) to be worked with field machinery, using the generally recommended methods for the region. Seedbeds were worked with a heavy-duty cultivator and harrow prior to seeding with a double disc press drill. Forage crops were underseeded with the preceding cereal crop. Recommended varieties were used, and changed over the course of the experiment. During 1958-1977 the fertilized treatments received standard annual additions of nitrogen and phosphorus fertilizer, applied as ammonium-nitrate-phosphate (23-23-0) or mono-ammonium phosphate (11-48-0). Fertilizers have been applied based on soil test analysis since 1978.

Herbicides were used for weed control, with 2,4-D and MCPA for broadleaf weed control, and borban and then triallate for wild oat control used in early years. Bromoxynil plus MCPA (1:1) for broadleaf weeds, and dichlofop methyl for wild oat control has been used in recent years. Glyphosate (Roundup) has been used for spot treatment of perennial weeds such as Canada thistle and quackgrass. Weed control on summerfallow was by tillage, usually requiring 4 to 6 operations with a heavy duty cultivator.

Cereal crops were swathed at the full-ripe stage, threshed with a conventional combine, with grain from each individual plot measured for yield estimation.

EXPERIMENTAL METHODS

Soils

The experiment was located on an Indian Head heavy clay soil, on nearly level topography. The dominant kind of soil profile is a Rego Black, with a black A horizon, over dark gray subsoil that is calcareous. The soils are not saline. The soils have a clay content of more than 60%, and form wide cracks when dry, with topsoil falling into cracks at the time of re-wetting by rain.

Rotations Included in Our Study

We evaluated five of the original ten rotations:

Cont. W - continuous wheat, fertilized*,

FWW (N+P, + straw) - fallow-wheat-wheat, fertilized*, straw returned,

FWW (N+P, - straw) - fallow-wheat-wheat, fertilized*, straw removed,

FWWHHH - fallow-wheat, wheat (underseeded to hay)-hay-hay-hay, with no fertilizer added,

FW - fallow-wheat (no fertilizer).

*The summerfallow-seeded crops received 6 kg N and 22 kg P per hectare until 1977, then slightly less P, on average, according to soil test recommendation.

*The stubble-seeded crops received 18-24 kg N and 21-22 kg P per hectare until 1977, then N rates of 75 to 86 kg N per hectare based on soil test recommendation.

Table 1. Yields for rotations studied, 1960-84†.

	Yield kg/ha		
Rotation	1960-77	1978-84	1960-84
F-W (no fert.)	2284	2123	2239
FWW (N,P, straw)	2605	2404	2551
FWW (N,P, - straw)	2657	2504	2615
Cont. W (fert.)	1629	2278	1810
FWWHHH (no fert.)	1870	1774	1843

†More complete yield tabulation are available in Zentner et al. (1987).

RESULTS AND DISCUSSION

Soil Variability

It is important that comparisons of the effects of rotations on soils be made only on soils that are similar in basic properties. We considered differences due to the natural variation in soil texture resulting from the way the original parent material was deposited, and differences resulting from the way plots and roadways were laid out, and tillage performed. We evaluated variability by systematically sampling two transects: one ran east to west and included 50 sites at 3.1 metre intervals; the second 50 site transect with 4.6 metre intervals began at the south end of the experimental field and ran north through the middle of plot 24, and across roadways from Range 1 to 6.

At each sample site a soil pit was dug, the A and B (if present) horizon thicknesses measured, and depth to calcium or lime carbonate determined. Samples of the cultivated layer (Ap), and horizon directly below (Bm horizon or Ck horizon) were taken.

Sand content was used as a measure of textural variability, mainly because it is relatively easy to determine, and sand was thought to be a sensitive indicator of textural differences in these heavy clay soils, even though the sand content ranged from only 5 to 10% in most soils. Sand was determined after reacting soil with dilute (1.0 M) hydrochloric acid and hydrogen peroxide to remove carbonate minerals and organic matter, which both function to cement individual particles into larger aggregates.

The sand content along the east-west transect was relatively similar at about 5-8% in all Ap horizons, with slightly less sand in the C horizons, and a slight increase in sand content in the far western part of the experimental area (Figure 1). Similar sand contents were observed in the soils along the north-south transect (Figure 2), except for markedly higher sand contents beginning midway through Range 5 and extending into Range 6. The soils with higher sand content were visibly different, both by hand-texture and they had much more strongly developed soil profiles. Similarly, Moss and Clayton (1941) reported sandier, partly sorted soils often bordering creekbeds and transitional areas. We decided to

Figure 1. Trend in Sand content along the East-West Transect through Range 3

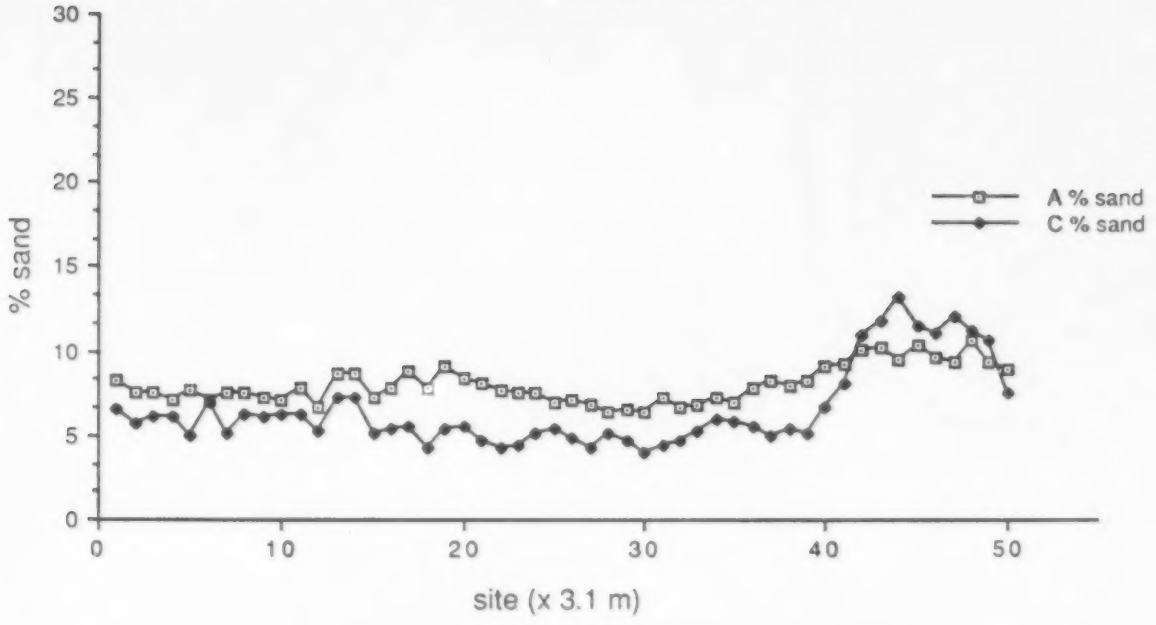
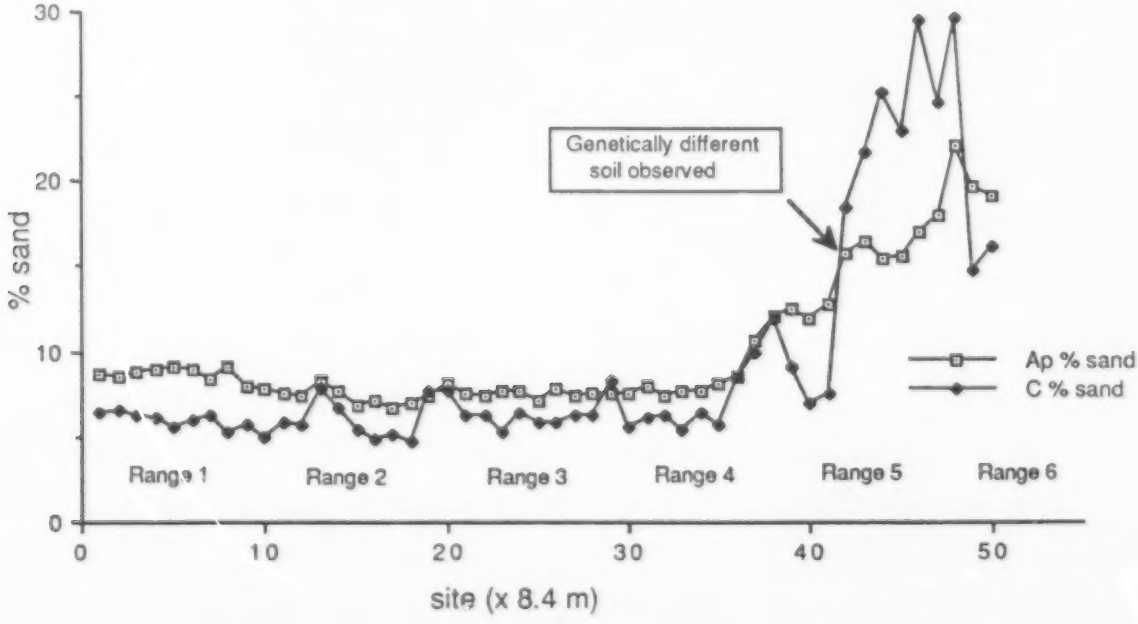


Figure 2. Trend in sand content along South - North transect



exclude the replicates falling in Ranges 5 and 6 from the study, because the soils were basically different in texture.

The plot of trends in depth of Ap horizon (including all soil mixed by cultivation, at present or in the past) and nitrogen (N) content (Figure 3) indicates the effect of the tillage in moving soil from the plots to the edge of the roadways. Most roadways have soils with very thick Ap horizons, most likely a result of the build-up of soil moved off the plot by the cultivator. Similarly, the N content of soils under roadways is higher, probably a result of the deposition (rather than loss) of topsoil and the permanent forage grown there. There appeared to be a trend to thinner Ap horizons in certain plots, probably because of the loss of soil by erosion, as discussed later in this report.

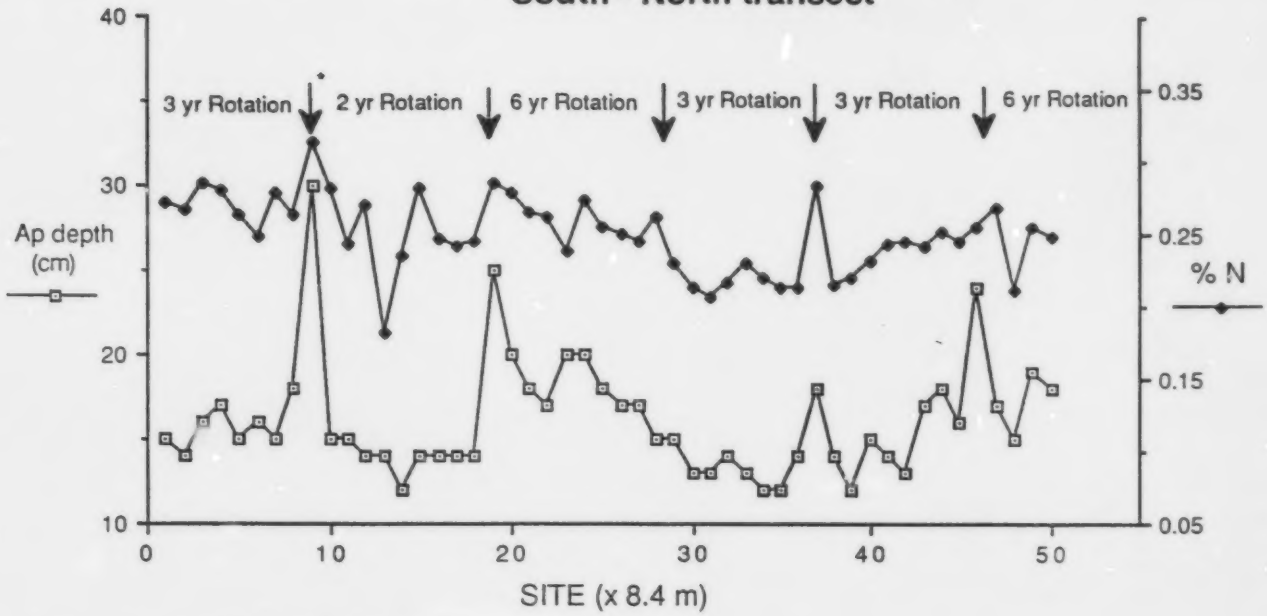
Organic Matter Content

Various rotations, particularly rotations involving summerfallow and forages, can result in differences in the organic matter content of soils. We evaluated organic matter by measuring organic carbon content (the main component of organic matter), nitrogen and sulphur contents, which are both important nutrients contained in organic matter.

The lowest organic carbon of the 0 to 7.5 cm depths (1.99% organic C) occurred in the F-W soils (Table 2a), with slightly higher but not statistically different organic C contents in the FWW rotations, with or without straw returned. The organic carbon content was highest in the FWWHHH and Cont. W rotations, probably because of larger amounts of residues returned to the soil and less frequent or no summerfallow.

Nitrogen contents followed the same order as organic carbon, with levels in soil under continuous wheat or the hay rotation higher. The higher nitrogen under continuous wheat is probably due to the absence of summerfallow, and the high rates of nitrogen fertilizer applied for seven years (1978-84). The higher nitrogen under the FWWHHH rotation probably is the result of nitrogen fixation by alfalfa, and the large amount of root residues that build up under forage. Sulphur was similar in all soils except for continuous

Figure 3. Trends in Depth of Ap and % N along the South - North transect



*Note: Arrows indicate sites located on roadways

Table 2a. Organic Carbon, Nitrogen and Total Sulfur in the 0 to 7.5 cm depth

ROTATION	OC%	ON%	S%	C:N:S
FW	1.99b*	0.189b	0.029b	69 : 6.6 : 1
FWW (N+P); + straw	2.14b	0.207b	0.028b	76 : 7.4 : 1
FWW (N+P); - straw	2.11b	0.205b	0.024b	89 : 8.7 : 1
FWWHHH	2.38a	0.231a	0.024b	101 : 9.8 : 1
W cont.	2.40a	0.232a	0.037a	64 : 6.2 : 1

* means not sharing the same letter are significantly different (P = 0.05). (Fisher protected LSD)

Table 2b. Organic Carbon, Nitrogen and Total Sulfur in the 7.5 to 15 cm depth

ROTATION	OC%	ON%	S%	C:N:S
FW	1.79	0.173	0.029	62 : 6 : 1
FWW (N+P); + straw	2.12	0.196	0.029	73 : 6.8 : 1
FWW (N+P); - straw	1.92	0.184	0.025	76 : 7.3 : 1
FWWHHH	2.04	0.193	0.024	85 : 8.1 : 1
W cont.	1.91	0.185	0.034	56 : 5.4 : 1

all means are not significantly different (by ANOVA)

Table 2c. Organic Carbon, Nitrogen and Total Sulfur in the 15 to 30 cm depth

ROTATION	OC%	ON%	S%	C:N:S
FW	1.65	0.144	0.028	60 : 5.2 : 1
FWW (N+P); + straw	1.83	0.170	0.032	57 : 5.3 : 1
FWW (N+P); - straw	1.55	0.153	0.025	62 : 6.1 : 1
FWWHHH	1.31	0.144	0.023	57 : 6.2 : 1
W cont.	1.63	0.153	0.030	55 : 5.2 : 1

all means are not significantly different (by ANOVA)

wheat, where it was significantly above the values for other rotations. The sulphur content of the soil under the hay rotation was low, and the amount of sulphur in the organic matter was less, as shown by the C:N:S ratio of 101:9.8:1. The low sulphur in soils under hay probably is a result of the extra sulphur removed in the hay in that alfalfa requires more sulphur than wheat. Sulphur, unlike nitrogen, must be obtained by alfalfa from the store in the soil organic matter.

Effect of Soil Movement by Tillage and Erosion on Soils of Plots

Initial observation made in the field and the plots of Ap horizon thickness that were presented earlier indicated the significant effects of soil movement by tillage in these relatively small plots. It is known as well, that clay soils are particularly vulnerable to wind erosion in early spring if not protected by crop residues or vegetation. The objectives of this portion of the study was to estimate soil loss from the plot areas using the cesium-137 method, and compare soil losses with soil properties important to determining erosion resistance, the organic matter content of soils and proportion of large aggregates that are considered non-erodible by wind. Aggregates or particles greater than 0.83 mm in size are considered too large to be picked up by wind, in contrast to smaller aggregates or particles of fine sand or silt size (0.02 to 0.100 mm) that are easily moved by wind.

Cesium-137 is a radionuclide produced by nuclear explosions, with large amounts added to the atmosphere by nuclear weapons testing in the 1958 to early 1960 period. The cesium came down with rain or snow, and is thought to have been uniformly distributed over the land, and tightly attached to soil, especially to clay and organic matter (de Jong et al. 1983). Measuring the present amount (on an area basis) of cesium in the soil, in comparison to a soil under grass that has not been eroded, gives a measure of soil loss due to erosion, or gain due to deposition.

Soil samples for cesium measurement were taken in October 1987, 30 years since the plots were established, and about 30 years since the main deposition of the cesium.

Samples were obtained using a coring device from the 0-7.5, 7.5-15 and 15 to 30 cm depths, bulk densities determined, and the cesium-137 content determined as outlined by de Jong et al. (1982). Total soil lost was estimated from the weighted content of cesium-137 in the 0 to 7.5 and 7.5 to 15 cm layers in treated and control sites since tillage and cracking may incorporate cesium-137 below the surface 0 to 7.5 cm layer. Soil loss was also estimated from 0 to 7.5 cm layer to elucidate the relationship between organic C and soil lost from the organic matter rich surface.

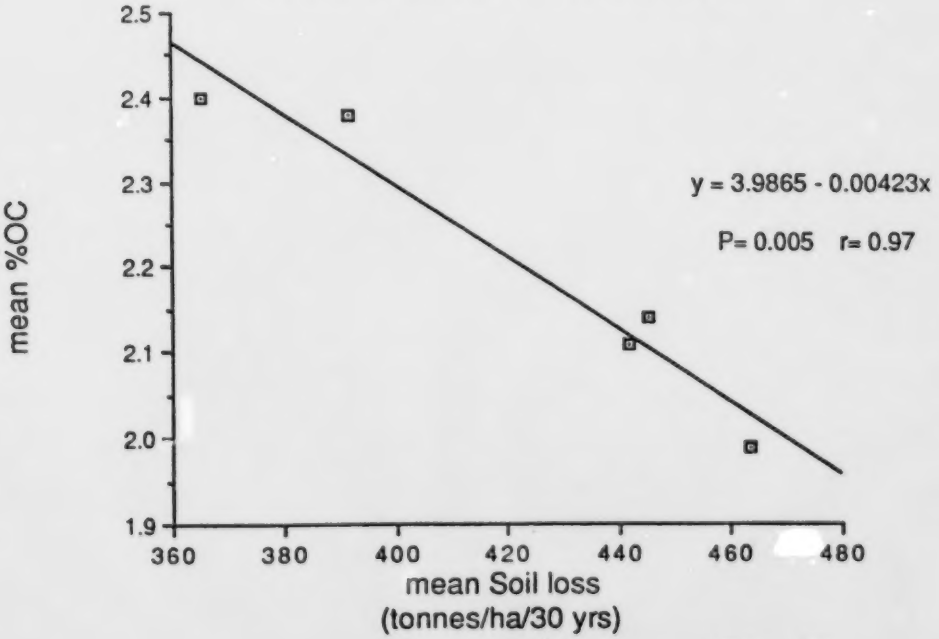
All plots contained less cesium than the non-eroded references sites, indicating a substantial loss (or removal) of soil from the cropped plots. Total soil losses ranged from 400 to about 1000 tonnes per hectare (t/ha) over the 30 year period (Table 3). We estimate that 1 mm depth of soil weighs 12 t/ha at Indian Head, indicating an average net loss of 37 to 83 mm or two to three inches of soil from the plot areas. Such estimates of topsoil removal from small plots are highly variable since erosive forces (i.e. windspeed and saltation of particles) are moderated by the surrounding plots. Nevertheless, the estimates of soil loss on the two year and three year and six year rotations can explain the differences observed in the depth of the Ap horizon. Soil lost from the two year, three year and six year rotations (8.3, 6.5 and 3.7 cm, respectively) when added to the present depth of the Ap for each rotation (Figure 3), suggest that a uniform Ap, 22 cm deep, existed at the start of the experiment.

Losses of organic matter rich surface soil (0 to 7.5 cm) were lower than the losses estimated on a 0 to 15 cm plow layer, but followed a similar trend with rotation treatment. The F-W rotation lost the most soil over the 30 years, with moderate losses from the FWW rotation, and smallest soil losses from the Cont. W and FWWHHH (Table 3). The F-W rotation had, of course, the highest frequency of summerfallow and the most tillage operations. Removal of straw from the one FWW rotation appears to have had little effect on erosion or organic matter (Tables 2a and 3). Simple regression analysis between soil lost from the 0 to 7.5 cm layer and present day organic C suggests that topsoil removal

Table 3. Soil loss and physical properties in the surface (0 to 7.5 cm) layer

	Rotation Treatment						
	FWWHHH	Cont. W	FWW (N+P:+straw)	FWW (N+P:straw)	FW	lsd	%CV
Soil loss 0-15 cm (t/ha/30 yrs)	446.2	699.6	708.7	721.94	1001.8	NS	31.6
Soil loss 0-7.5 cm (t/ha/30 yrs)	365.5	391.6	445.3	441.7	463.6	NS	9.6
Bulk Den. (gm/cm^3)	0.89	0.95	0.93	0.95	1.02	NS	7.9
MWD (wet sieved)	0.32	0.33	0.26	0.26	0.25	NS	13.3
% > 0.83 mm	71.4	70.2	64.8	64.1	61.9	5.2	4.1
% Mechanically stable fraction	85.0	86.7	80.7	80.5	75.8	4.4	2.8
% Turbidimetric agg. stability	86.6	87.8	83.4	85.2	82.0	4.1	2.7

Figure 4. Relationship between Organic Carbon and Soil lost in the surface 0 - 7.5 cm layer



significantly depleted organic C levels (Figure 4). Based on this linear relationship, non-eroded plots should contain 3.99% organic C. If rotation treatments are responsible for soil loss, the organic matter level (1.724 x % organic C) prior to the experiment should be similar to the value estimated assuming no erosion. Samples taken from this site in 1961 were found to contain 7.38% organic matter which is in close agreement with the estimated value of 6.88% organic matter.

The relative effects of tillage in dragging soil off the plots to the roadways and erosion to soil loss is difficult to separate. Significant erosion, probably by wind, is evident in the strong statistical relationships between soil loss and soil properties important to erosion. Soil loss was greatest where the proportion of non-erodible aggregates was lowest, and decreases as the proportion of non-erodible aggregates (> 0.83 mm) increases (Figure 5). There are more non-erodible aggregates in soils with higher organic carbon contents (Figure 6), and soils with more organic matter (more organic carbon and nitrogen) have the lowest soil losses. The higher organic matter contents are mainly in the FWWHHH and Cont. W rotations. These treatments are tilled less often (minimizing soil movement by tillage) and have the lowest frequency of summerfallow when soils are susceptible to wind erosion.

Substantial movement of soil by tillage is indicated by the over-thickened Ap horizons there, and the roadways are noticeably higher than the plot areas in many cases (Photograph 1). The area of roadway is about one-seventh of the area of plots. If all soil lost from plots was moved by tillage to the roadways, the roadways should have gained about 26 to 58 cm of soil, based on losses of 3.7 to 8.3 cm from the plots. The roadways have gained soil (Figure 3), but not that much. Our best estimate is that movement of soil by tillage has resulted in a substantial proportion of the soil loss from plot areas, and that wind erosion has resulted in significant soil losses, particularly on F-W and FWW rotations.

Figure 5. Relationship between the percent non erodible fraction and soil lost from the surface 0 - 7.5 cm layer

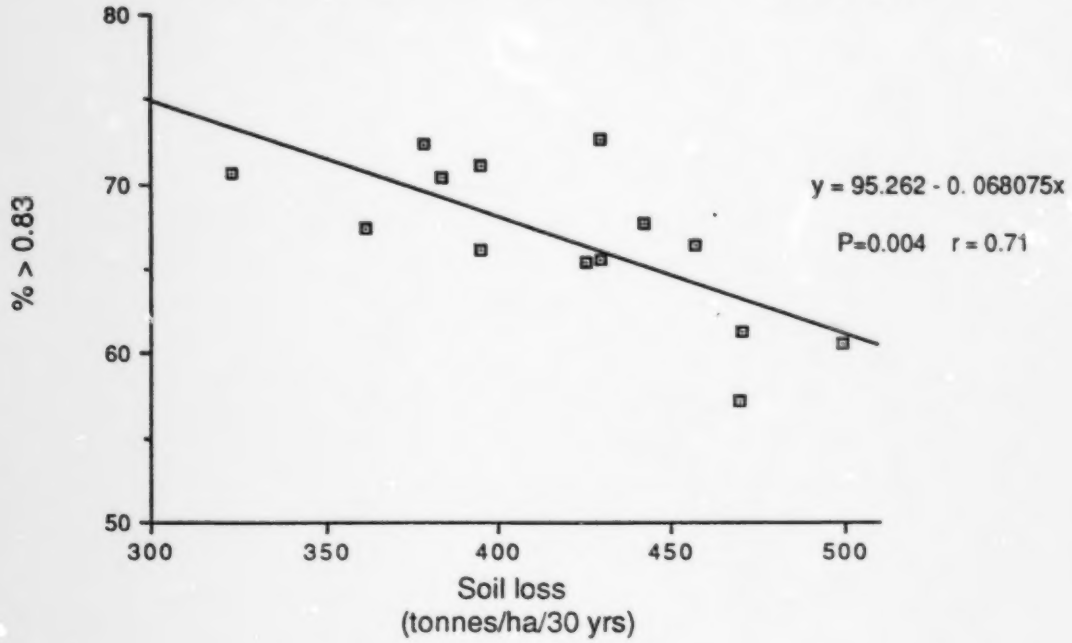
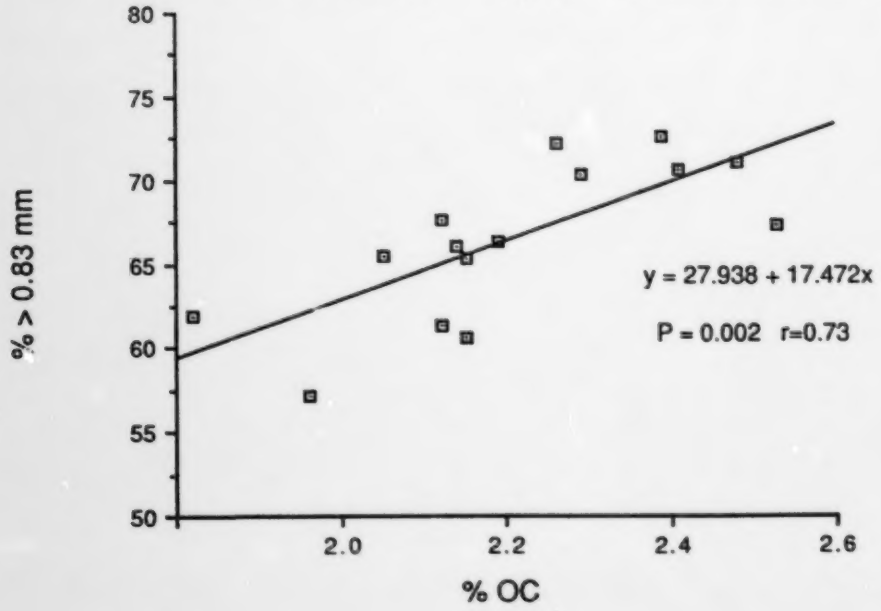


Figure 6. Relationship between Organic C level and the amount of Non Erodible fraction > 0.83 mm



Photograph 1: A view looking east at the north end of one range of plots, illustrating the accumulation of soil moved from the plot by tillage operations.

Photograph 2: A plot that was summerfallow in 1986, photographed in May, 1987. Mechanical tillage reduces residue protection, and leaves soils susceptible to wind erosion.

Soil Tilth

Good soil tilth depends primarily on a loose, porous and stable assemblage of aggregates. Mean weight diameter (MWD) describes the size distribution of aggregates. Cont. W and FWWHHH rotations had the highest MWD or a greater proportion of larger, water stable aggregates (Table 3). FWW and FW rotations contained fewer large aggregates.

Dry sieving revealed a similar ranking of rotation treatments. FW had the lowest percentage of large (>0.83 mm) non-erodible aggregates and the aggregates were least resistant to mechanical abrasion during resieving. Cont. W and FWHHH had the largest percentage of non-erodible aggregates as well as the highest mechanical stability. Removal of straw by baling did not significantly effect the proportion or stability of non-erodible aggregates.

Turbidimetric stability determines the ability of aggregates to resist dispersion in water. The trend in rotation treatments is similar (Table 3) to other determinations of aggregation and aggregate stability. Aggregates from the FW had significantly less resistance to dispersion than the Cont. W or FWWHHH rotations, with the three year rotations possessing an intermediate stability.

Soil bulk density gives an indication of the degree of structure and pore space. Although not significantly affected by treatment, the trend across rotation treatments is concordant with other indicators of soil tilth. High density in the FW rotations is likely a result of the large proportion of smaller aggregates which afford more efficient packing and less pore space. Rotations with larger more stable aggregates generally show lower densities and more pore space.

Nutrient Supplying Capacity

Nitrogen (N) and sulphur (S) are supplied to plants as a result of organic matter breakdown by microorganisms. Soils which have large amounts of decomposable organic matter are likely to possess an active microbial population and a greater capacity to supply

N and S. Soil samples from the rotation treatments were incubated at 25°C in the laboratory, and leached at successive time intervals to remove nitrate and sulphate. Cont. W and FWWHHH mineralized significantly more N and S (Figures 7 and 8) than the FWW rotations, with the 2 year rotation supplying the least. Carbon respired (or mineralized) over the first two weeks of a similar study (Figure 9) revealed a similar ranking of rotation treatments.

Thirty years of straw removal by baling did not significantly alter the N and S supplying capacity or the microbial populations. Quantification of microbial biomass size and field accumulation of nitrate and ammonium during the fallow period of 1983 supported this conclusion (Figures 10 and 11). The presence of N-rich root residues from the hay stand probably accounted for the significantly higher mineralization in the field during the fallow period (Greer and Anderson, 1989). However, addition of hay residues 3 years out of six does not seem to significantly improve the N supply over Cont. W (Figure 7). Such results suggests that, over the long term, residue additions are probably secondary to topsoil erosion in determining the overall organic matter levels and subsequent nutrient supplying power on these plots.

Few significant treatment effects below the 7.5 cm depth (Tables 2b and 2c; Figures 12 through 17) is further testimony to the importance of the topsoil. Rotation treatments which deplete and dilute the topsoil with subsoil will over time result in lower quality soil.

CONCLUSIONS AND IMPACT

This study is the most comprehensive evaluation of the effect on soils of the long-term rotations at Indian Head. The study identified portions of the experimental area where the use of the data in comparisons is limited by soil variability. Substantial losses of soil from the plot areas were indicated by the cesium measurements, and thought to be due to mechanical movement of soil during tillage operations, and to wind erosion. The thickness of surface A horizons was reduced by as much as 8 cm by soil losses from the two year

Figure 7. Cumulative N mineralized from the 0 to 7.5 depth during 24 week laboratory incubation

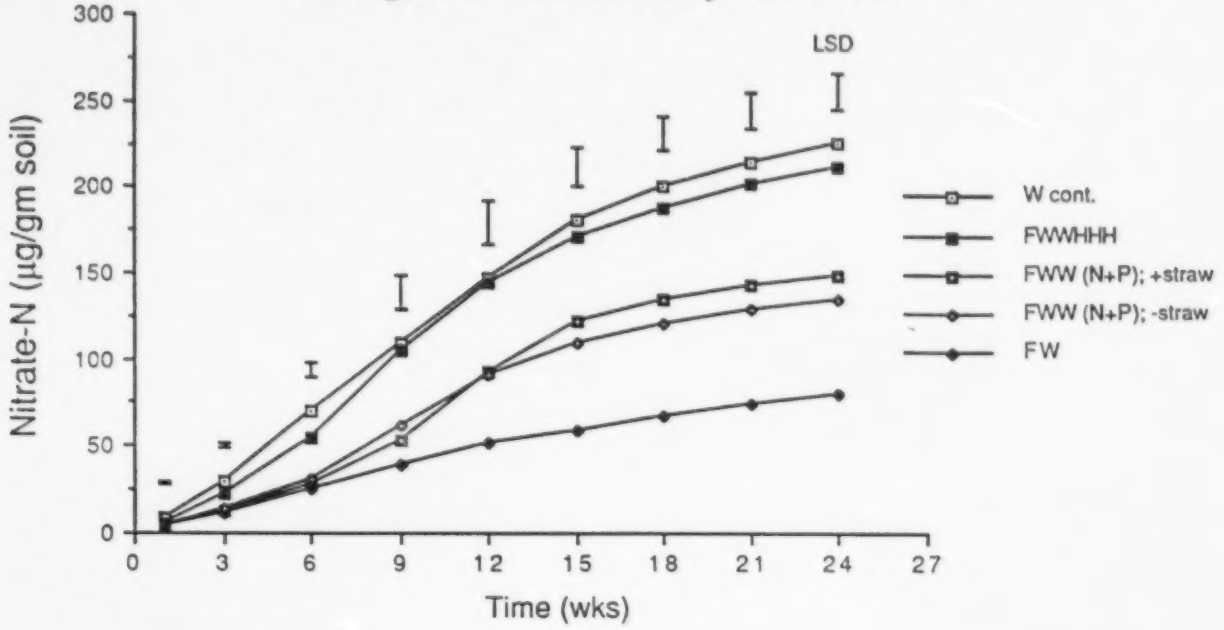


Figure 8. Cumulative S mineralized from the 0 to 7.5 cm depth during a 24 week laboratory incubation

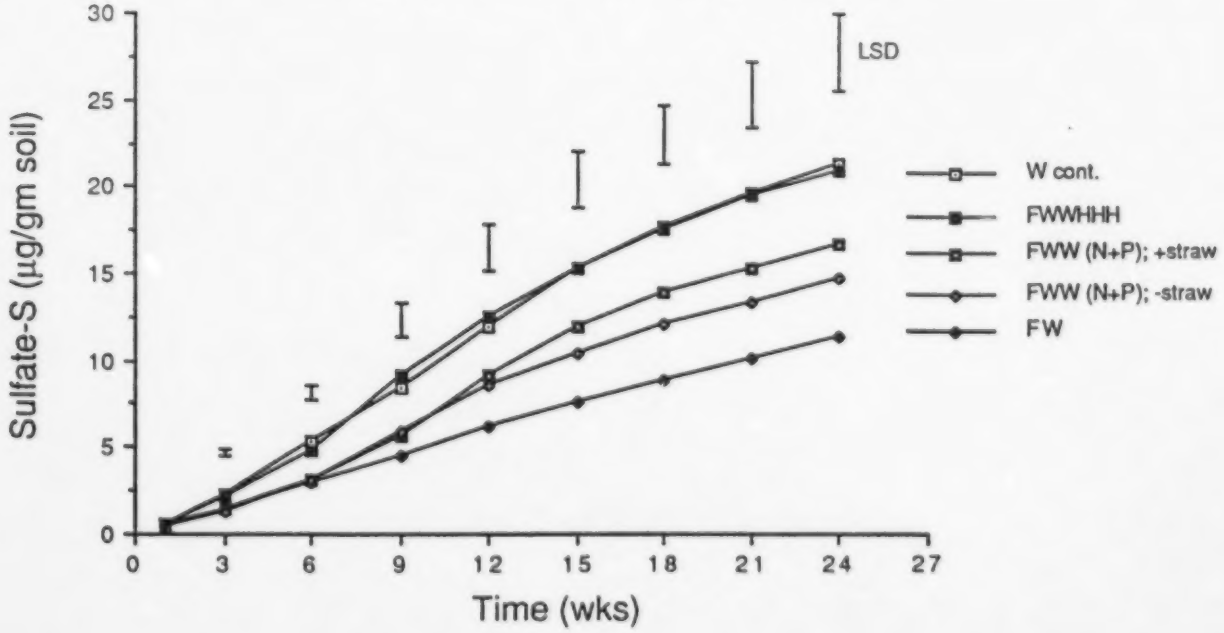


Figure 9. Cumulative C mineralized from the 0 to 7.5 cm depth during a 14 day laboratory incubation

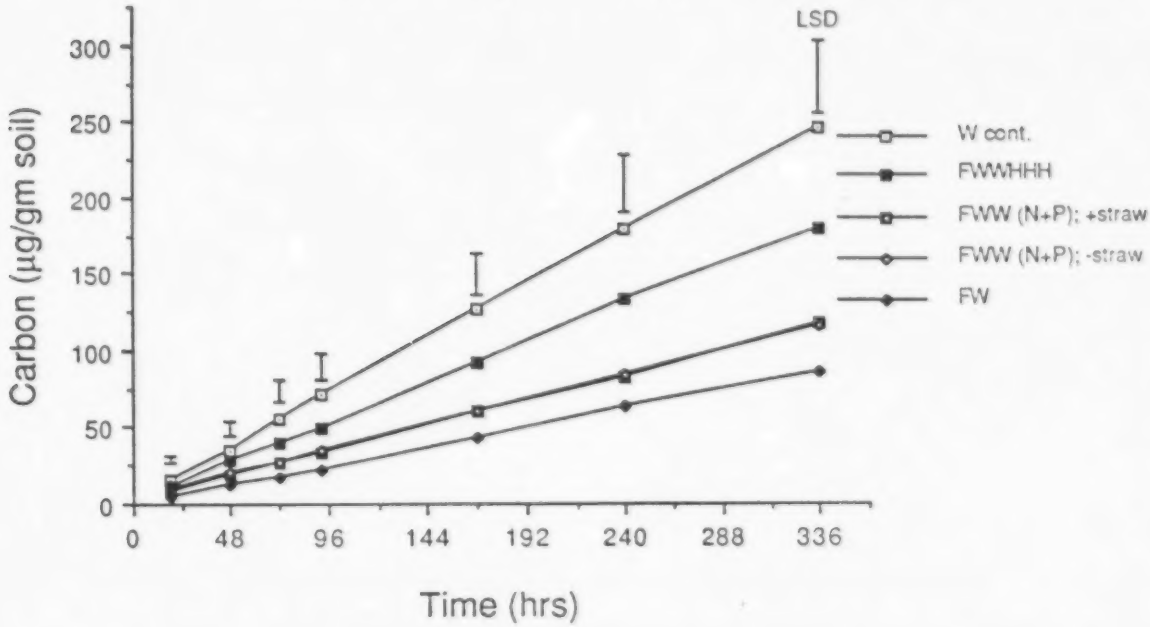


Figure 10. Mean Microbial Biomass Carbon over the summer of 1988 as influenced by Rotation

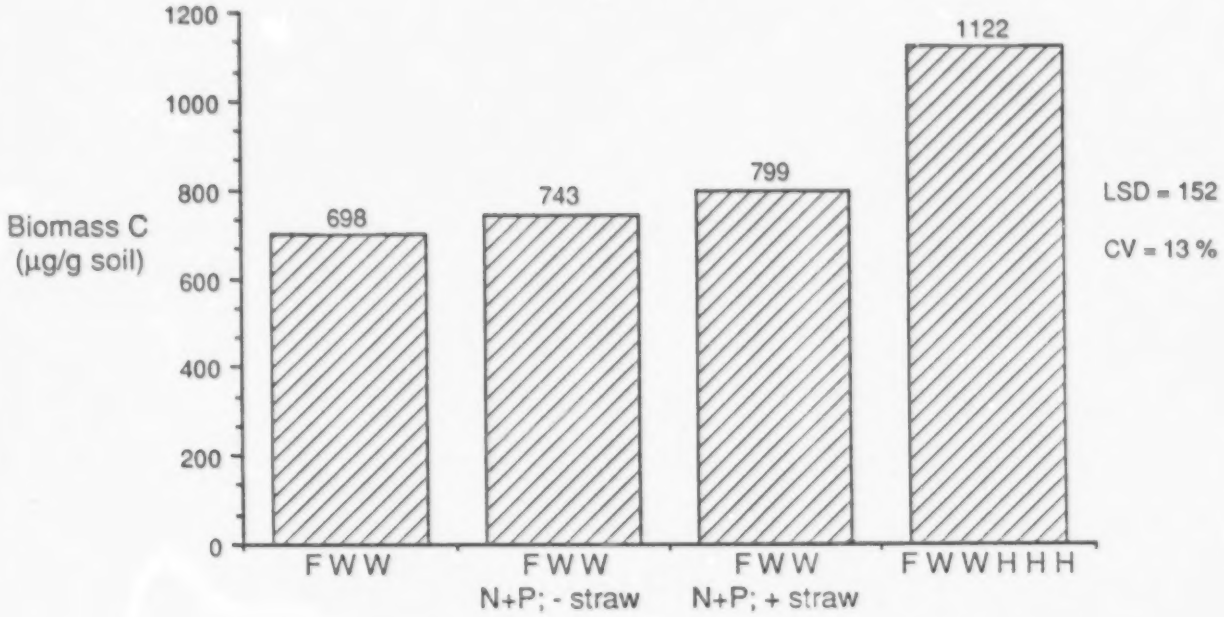


Figure 11. Mineral N (nitrate & ammonium) present to 30 cm on August 12/88

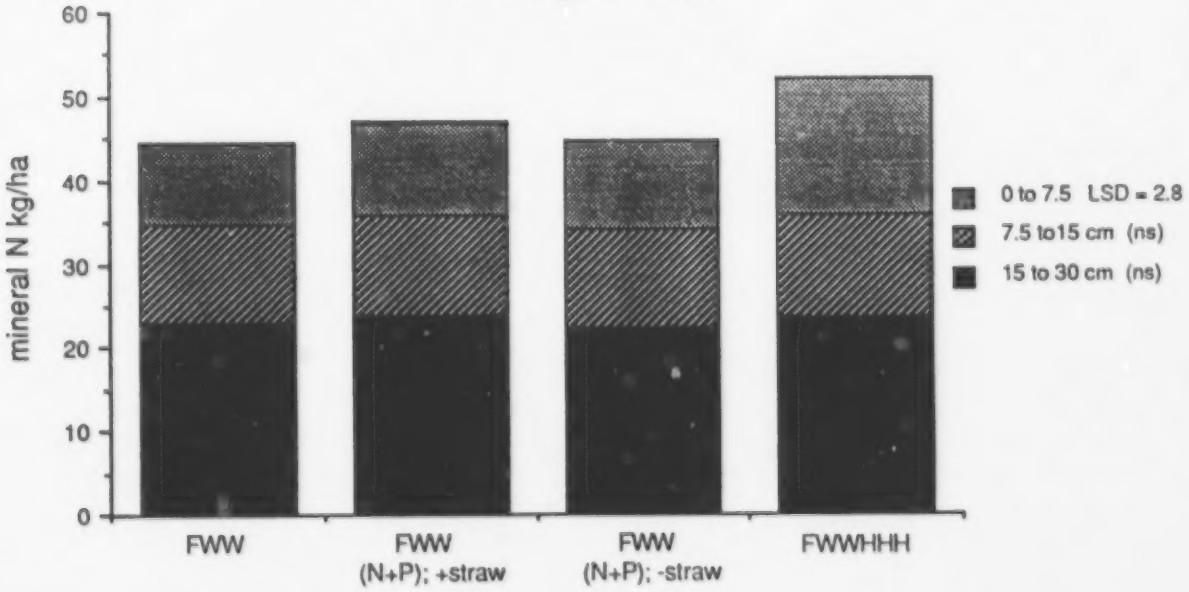


Figure 12. Cumulative N mineralized from the 7.5 to 15 cm depth during a 24 week laboratory incubation

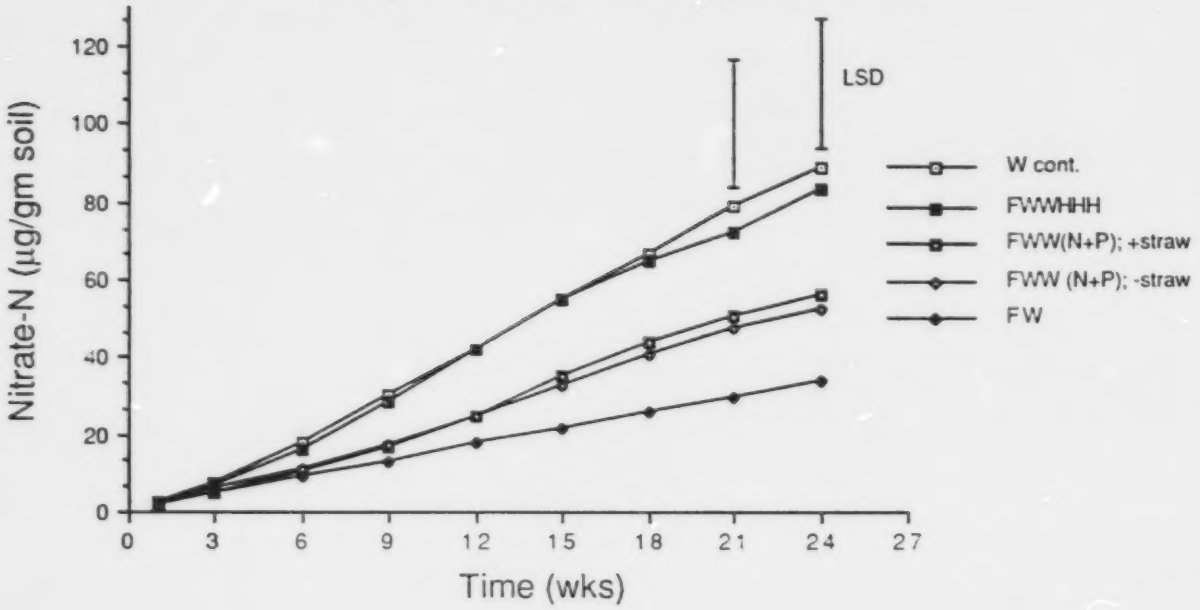


Figure 13. Cumulative N mineralized from the 15 to 30 cm depth during a 24 week laboratory incubation

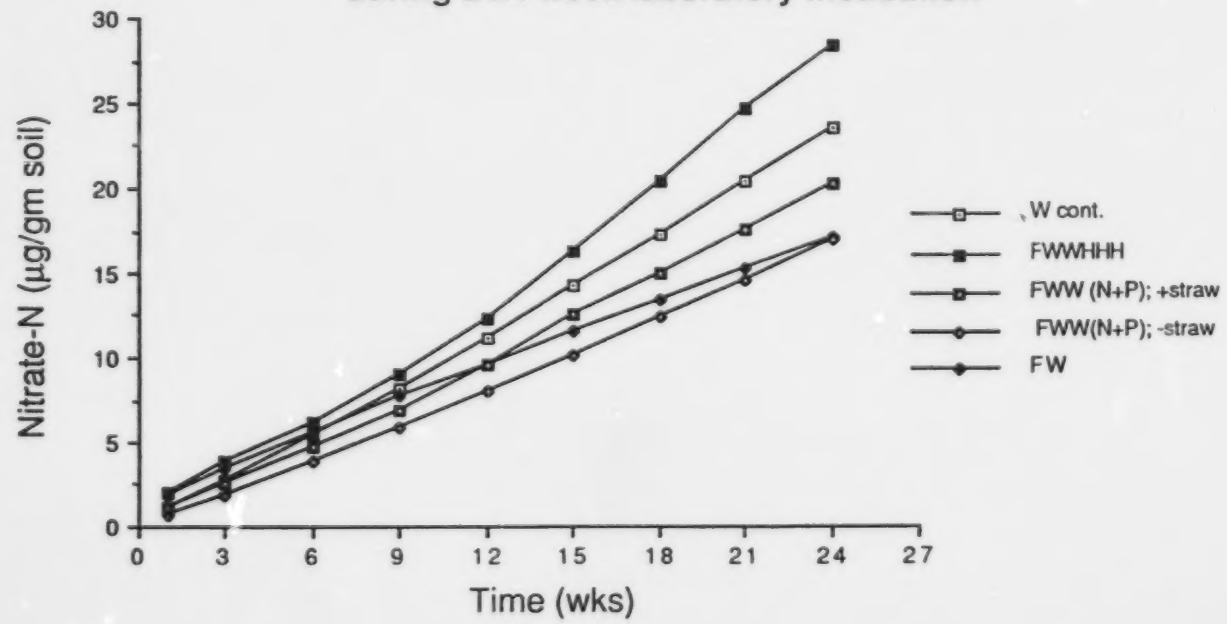


Figure 14. Cumulative S mineralized from the 7.5 to 15 cm depth during a 24 week laboratory incubation

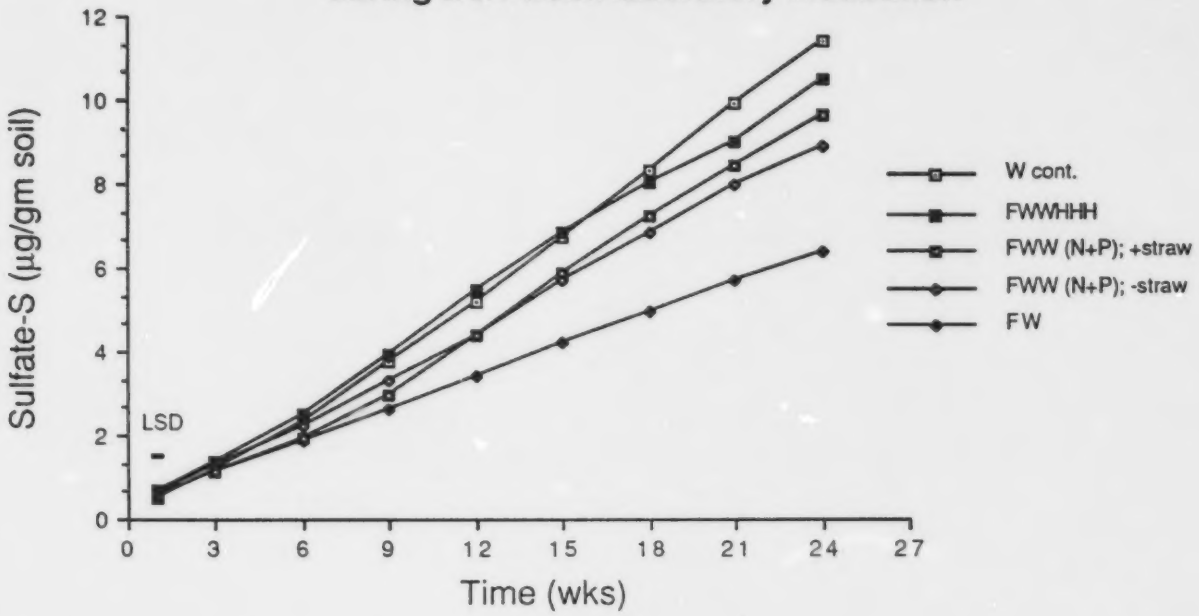


Figure 15. Cumulative S mineralized from the 15 to 30 cm depth during a 24 week laboratory incubation

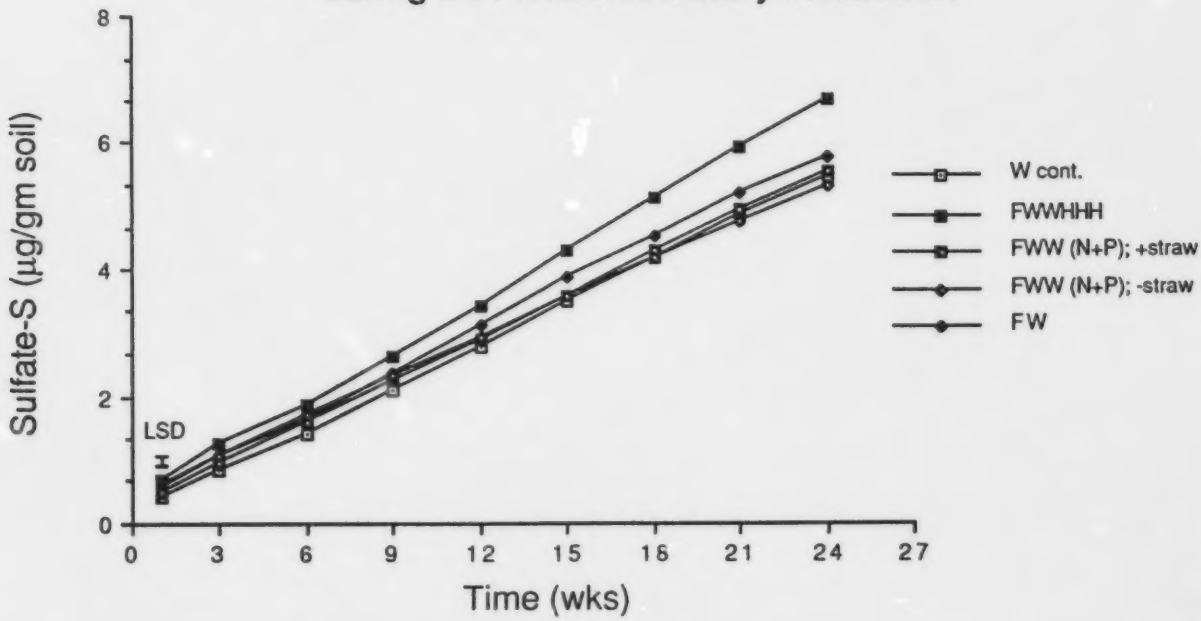


Figure 16. Cumulative C mineralized from the 7.5 to 15 cm depth during a 14 day laboratory incubation

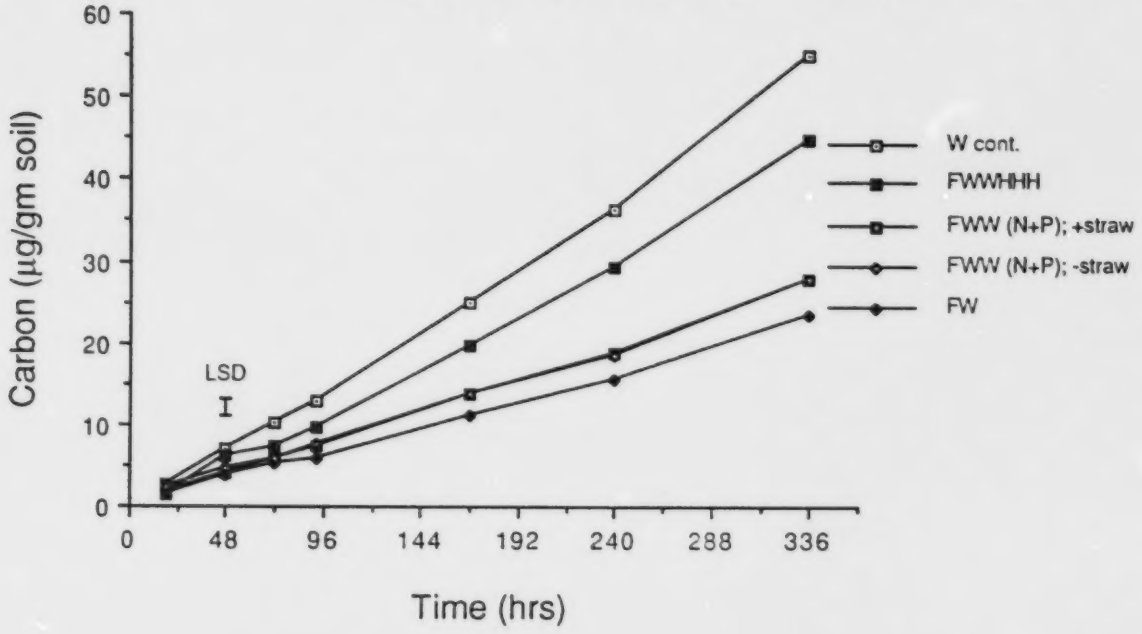
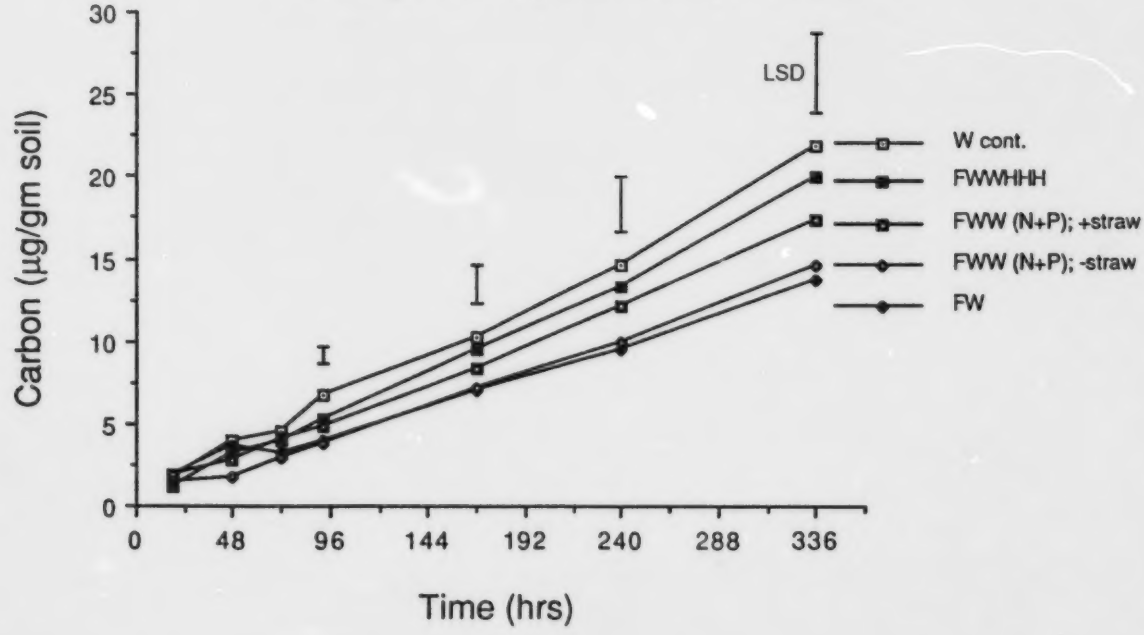


Figure 17. Cumulative C mineralized from the 15 to 30 cm depth during a 14 day laboratory incubation



wheat-fallow rotation. The soil-conserving attributes of the continuous wheat (with adequate fertilizers added since 1978) and the wheat-hay-fallow rotations were indicated by reduced soil losses, higher organic matter contents, and a larger and more active microbial population that was able to produce increased amounts of plant available nitrogen and sulphur, in laboratory experiments and in the field.

This study has two major impacts. One is to further document the soil-deteriorating effects of two and, to a lesser degree, three year wheat-summerfallow rotations, particularly where no fertilizer is used; and to indicate the soil-conserving attributes of continuous wheat and wheat-hay rotations. The second impact is to indicate the need for field-scale evaluations of rotation effects, in order to remove effects resulting from tillage on relatively small plots.

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LIST OF PAPERS PREPARED PAPERS AND TALKS

Papers and Thesis

Greer, K.J. and D.W. Anderson. 1989. Dynamics of microbial biomass carbon and nitrogen and extractable nitrate in long term rotation studies at Indian Head. Proc. of Soils and Crops Workshop, University of Saskatchewan, Saskatoon, Sask.

Greer, K.J. and D.W. Anderson. 1989. The role of partially humified organic matter in nitrogen turnover. Canadian Soil Science Society Technical Meeting, July 1989, Montreal, Quebec.

Greer, K.J. 1989. The effect of long-term rotations at Indian Head on organic matter, soil tilth and erosion. M.Sc. Thesis, Department of Soil Science, University of Saskatchewan, Saskatoon, Sask. June 1989.

Talks

D.W. Anderson: Some of these data used in extension presentations at:

a) Saskatchewan Seed Growers Association, January, 1989

b) Soils and Crops Workshop, 1989

c) Rural Development Extension Meeting, Lloydminster

and others.

Personnel Involved

K.J. Greer	100%
D.W. Anderson	8% (ADF Strategic Grant)
D. Brock	(5% - ADF Strategic Grant)